Diboson Physics Study with ATLAS

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The ATLAS prospects for the measurements of the $WW$, $WZ$ and $W\gamma$ cross sections and the limits on the anomalous $WWZ$ and $WW\gamma$ couplings at 14 TeV are summarized. The strategy to extract the signal and measure the triple gauge boson couplings is presented, focusing on early LHC data-taking. The results are obtained with full simulations of ATLAS detector, with included trigger selection, detector calibration and alignment corrections.
Introduction. The local gauge symmetry of the Standard Model (SM) generates self interactions of the gauge fields which manifest themselves as a coupling of three or four gauge bosons such as $WWZ$, $WW\gamma$ or $WWZ\gamma$. Within the SM the structure and the strength of these couplings are completely determined by the $SU(2)_L \times U(1)_Y$ symmetry and precise measurement of these couplings can either additionally confirm the SM or may indicate a new physics at an unprobed energy scale. The production of diboson pairs at the LHC provides a direct test of $WWZ$ and $WW\gamma$ couplings at the highest possible energies.

In this report we summarize the most recent ATLAS results [1] on the strategy for study $WW$, $WZ$ and $W\gamma$ production and the prospects for probing the $WWZ$ and $WW\gamma$ triple gauge-boson couplings. These results are obtained with full simulation of the ATLAS detector, which include trigger selection, detector calibration and alignment corrections. For the analysis, the leptonic ($l = e$ or $\mu$) decay modes of $W$ and $Z$ vector bosons are used. Signal and main background processes are modeled with MC@NLO+HERWIG ($WW$, $WZ$, $ZZ$, $t\bar{t}$), PYTHIA ($W\gamma$, $Z$) and ALPGEN+HERWIG ($W/Z+\text{jets}$) generators.

WW production. At the LHC energies the $W$ pairs are produced through both quark-antiquark annihilation, $q\bar{q} \rightarrow W^+W^-$ ($\sim 95\%$) and gluon-gluon fusion, $gg \rightarrow W^+W^-$ ($\sim 5\%$). The total NLO cross section for $q\bar{q} \rightarrow W^+W^-$ production is $111.6$ pb, and $5.2$ pb for the leptonic ($l = e$, $\mu$) decay modes. The signature of the $WW$ fully leptonic final state is two high $p_T$ isolated leptons of opposite sign and large missing transverse energy ($E_T$). The events are triggered by a single isolated electron or muon with $p_T > 25$ GeV or $p_T > 20$ GeV. The trigger efficiency is $96-98\%$. Main background SM processes with similar signature are: $t\bar{t}$, $Z/\gamma'$, $W\pm Z$, $ZZ$, $W+\text{jets}/\gamma$ where the jet/$\gamma$ fakes an isolated electron or the jet contains a muon. Signal separation from the background (Fig.1) can be achieved with the following cuts: (1) two isolated leptons of opposite sign, with $p_T > 20$ GeV and $|\eta| < 2.5$; (2) no jets with $p_T^{\text{jet}} > 20$ GeV and $|\eta| < 3$; (3) $E_T > 50$ GeV; (4) $|M_{Z-m(l^+l^-)}| > 15$ GeV; (5) $\phi_\ell < 2$ rad, or $\Phi(p_T^\ell, p_T) > 175^\circ$. With $1 \, \text{fb}^{-1}$ of data, about 104 signal and 19 background events are expected. Multivariate Boosted Decision Trees (BDT) [2] technique can further improve signal efficiency. Using this technique, about 469 signal and about 92 background events are expected. The one-dimensional 95\% C. L. limits on anomalous $WWZ$ and $WW\gamma$ couplings [1] are: $-0.035 < \Delta \kappa_Z < 0.073$, $-0.040 < \lambda_Z < 0.038$, $-0.149 < \Delta g_2^Z < 0.309$, $-0.088 < \Delta \kappa_\gamma < 0.089$, and $-0.074 < \lambda_\gamma < 0.165$, for form factor scale $\Lambda_{FF} = 2$ TeV, and for $10 \, \text{fb}^{-1}$ of data. The two-dimensional 95\% C. L. limits with HISZ assumption [3], for various integrated luminosities are shown in Fig.1.

$W^\pm\gamma$ production. At the LHC, $W^\pm\gamma$ pairs are produced through $q\bar{q}'$ scattering. The total $W^\pm\gamma$ NLO cross section, for a photon $E_T^γ$ above 7 GeV and a lepton-photon separation $\Delta R(l, \gamma) > 0.7$, is predicted to be $451.6$ pb, dropping to $97.4$ pb if $W$ decays leptonically ($l = e$, $\mu$). The signature of $W\gamma$ is one isolated high $p_T$ lepton ($e$ or $\mu$), one isolated high $E_T^\gamma$ photon, and large $E_T$ from the $W$ neutrino. Three trigger types are investigated (isolated muon with $p_T > 20$ GeV, isolated electron with $p_T > 22$ GeV and photon with $E_T^\gamma > 50$ GeV) and trigger efficiency is $\approx 80\%$. The dominant background is inclusive $W$ production with final state radiation (FSR), $W+\text{jets}$ with jet mis-identified as photon and inclusive $Z$ production with one electron mis-identified as photon. The BDT method is used to select the $W^\pm\gamma$ events. Three trainings are done to separate $\gamma\gamma$ events with FSR photons, signal photons from fake photons, and signal photons from the contamination of $Z$ inclusive events. With $1 \, \text{fb}^{-1}$ of data, the expected number of $W^\pm\gamma$ and background events is $1604$.
and 1183 in $e\gamma\nu$ channel and 2166 and 1342 in $\mu\gamma\nu$ channel. The $k$ factors used for the signal and background corrections to NLO cross sections are 1.66 and 1.3. The expected limits on anomalous $WW\gamma$ couplings at 95% C.L. are: $-0.26 < \Delta\kappa_\gamma < 0.07$, $-0.05 < \lambda_\gamma < 0.02$, for $\Lambda_{FF} = 2$ TeV, and for 10 fb$^{-1}$ of data.

**$W^Z$ Production.** The NLO cross section for $W^Z$ production at 14 TeV is 47.8 pb, and 0.72 pb for leptonic ($l = e, \mu$) channels and $Z$ on mass shell. This process has a very distinct experimental signature with three high $p_T$ leptons and high $E_T$. At least two leptons must have like-flavour of opposite sign and invariant mass consistent with the mass of $Z$ boson. Background processes include $Z+\text{jets}$, $Z\gamma$, $ZZ$ and $t\bar{t}$ production. Signal extraction can be achieved with the following cuts: (1) two same-flavour opposite sign leptons, which satisfy $|M(ll) - M_Z| < 10$ GeV, and at least one with $p_T > 25$ GeV; (2) $E_T > 25$ GeV; (3) vector sum of jet transverse momenta less than 200 GeV; (4) vector sum of $p_T$ of charged leptons and $E_T$ less than 120 GeV; (5) third lepton (not from $Z$ decay) is required to have $p_T > 20$ GeV, and transverse mass $M_T$ determined by the third lepton $p_T$ and $E_T$ must be within $40 < M_T < 120$ GeV. For 1 fb$^{-1}$ of data 53 $WZ$ and 7 background events are expected. With BDT analysis the number of expected $WZ$ and background events is 128 and 16 respectively for 1 fb$^{-1}$ of data. Expected limits on anomalous $WWZ$ couplings at 95% C.L. are: $-0.095 < \Delta\kappa_Z < 0.222$, $-0.015 < \lambda_Z < 0.013$, and $-0.011 < \Delta g_1^Z < 0.034$, for $\Lambda_{FF} = 2$ TeV, and for 10 fb$^{-1}$ of data.

Summary. The increased energy and luminosity at the LHC will allow for substantial progress in diboson physics studies and marks a new sensitivity domain with respect to that currently available from the Tevatron data. The results show that ATLAS can measure the $WW$, $W\gamma$ and $WZ$ signal with early ($\approx 100$ pb$^{-1}$) LHC data. With 10 fb$^{-1}$ charged triple gauge boson couplings can be measured with an accuracy $\mathcal{O}(10^{-2})$ assuming $\Lambda_{FF} = 2$ TeV.

**References**

